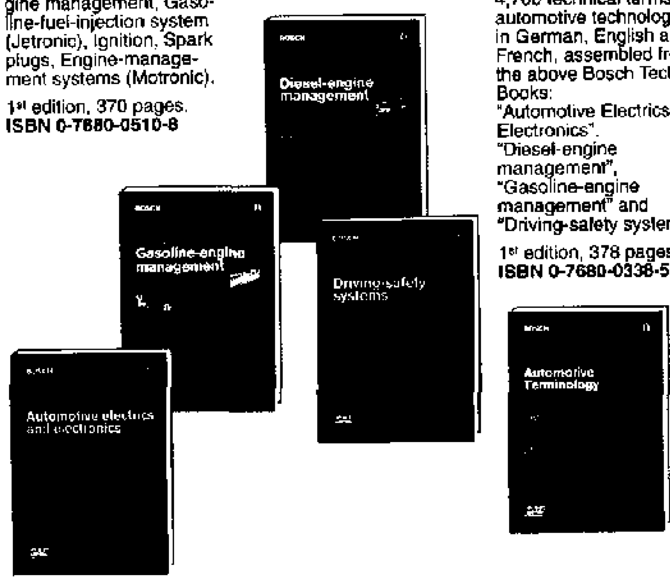

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Foreword to the 5th Edition

The "Automotive Handbook", a reliable guide full of up-to-date and concise information, has grown over a period of six decades from a calendar supplement of 96 pages to a 960-page reference work. In that time, over a million copies have been produced worldwide and the text translated into numerous languages.
The 5th edition, in common with its predecessors, is supported by two main pillars: the expertise of the technical staff at our company and in the automotive industry. They have fully revised the contents of this manual and brought it completely up to date. Thanks are due to all those involved.
This book is intended primarily as a source of important facts and figures and as a review of present-day technology for the automotive engineer and technician, but also for anyone else with an interest in technical matters. Accordingly, the automotive technology content is restricted to passenger cars and commercial vehicles, and the remaining content to that required for practical purposes.
Within the framework of a pocketbook it is impossible to present detailed coverage of individual technical subjects. On the other hand, bearing in mind the very wide range of readers, we do not want to dispense with generally applicable topics and data. However, we have dispensed with the "Conversion Tables" as the calculator is now an everyday item of equipment and any figure required can easily be calculated using the conversion formulas provided. The chapter "Road Traffic Legislation (Germany)" has also been deleted due to the international usage of the booklet.
These deletions have made way for new and updated topics which have added an extra 70 pages to the book.
We recommend readers to scan through the "Automotive Handbook" in order to gain an overall impression *before using it.*

The Editors

For your information

The following topics have been updated/extended since the 4th edition:
Vibration • Acoustics • Electronics (integrated circuits, micromechanics, mechatronics, sensors) • Statistics• Reliability • Closed and open-loop control systems • Materials technology (basic principles, materials, lubricants, fuels, consumables) • Corrosion • Hardness • Calculating fuel consumption • Vehicle dynamics.
Internal-combustion engines (direct fuel injection, diesel combustion systems) • Engine cooling (cooling-module technology, thermomanagement, exhaust cooling) • Turbochargers and superchargers (multistage) • Engine management on gasoline engines (mixture control, fuel-injection systems, fuel injectors, spark plugs, ME-Motronic, exhaust gases) • Engine management on diesel engines (axial/radial-piston pumps, injectors, exhaust gases, start-assist systems).
Electric drive units • Drivetrain (transmission, traction control systems (TCS) for passenger cars and commercial vehicles) • Steering • Braking systems (ABS for passenger cars, ABS and EBS for commercial vehicles) • Bodywork, commercial vehicles • Lighting systems (stepped reflectors, Bi-Litronic, headlamps and lights). Car radios • Park Pilot systems • Navigation systems • Vehicle information systems • Mobile phones • Safety and security systems (impact detection, interior-movement detection) • Automotive hydraulics (electric proportional control valves).
Circuit diagrams and symbols • Vehicle electrical system (batteries, battery testers, water-cooled alternators, electromagnetic compatibility (EMC))
Passenger-car specifications.

The following topics have been introduced:
Fuel filters • MED-Motronic • Natural gas operation (spark-ignition engines) • Fuel cells • EHB for passenger cars • Automatic Cruise Control (ACC) • Instrumentation • Traffic telematics • Car radios (DAB) • Connectors • Cartronic.
and the following have been dropped:
Conversion tables • Road traffic legislation (Germany).

the engine's pumping losses, and fuel consumption drops as a result. A specifically introduced residual exhaust-gas share can likewise influence combustion and thus the emission of nitrogen oxides (NO_X) and unburnt hydrocarbons (HC).

Control
In a spark-ignition engine with external mixture formation, the power output is proportional to the air mass flow drawn in. In future, it will also be possible to directly control the direct-injection SI engine operating with *lean A/F mixtures via variation* of the injected fuel mass.

Throttle valve
The throttle valve is used when the engine power, and thus (at a specific engine speed) the engine torque, are to be controlled by means of the air mass flow. When the throttle valve is not fully open, the air drawn in by the engine is throttled, thereby reducing the torque generated. This throttling effect is dependent on the position and thus on the opening cross-section of the throttle valve.

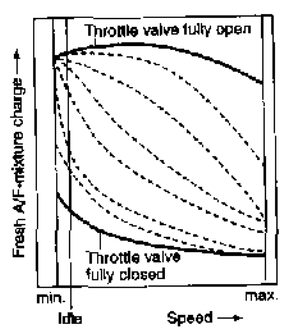
The maximum engine torque is achieved when the throttle valve is fully open (see Fig.).

Charge cycle
The charge cycle of fresh A/F mixture and residual exhaust gas is controlled by the appropriate opening and closing of the intake and exhaust valves. The cams on the camshaft determine the points at which the valves open and close (valve timing) and the course of the valve lift. This influences the charge-cycle process and thus also the amount of fresh A/F mixture available for combustion.

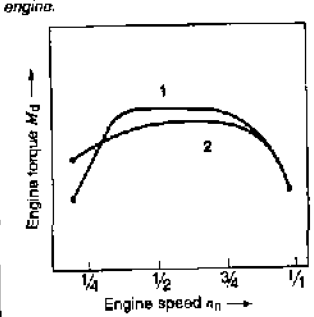
The valve overlap, i.e. the overlapping of the opening times of the intake and exhaust valves, has a decisive impact on the residual exhaust-gas mass in the cylinder. This situation involves "interior" exhaust-gas recirculation. The residual exhaust-gas mass can also be increased by "exterior" exhaust-gas recirculation. In this case, an additional EGR valve connects the intake manifold and exhaust manifold. When the valve is open, the engine draws in a mix of fresh A/F mixture and exhaust gas.

Supercharging
The obtainable torque is proportional to the charge of fresh A/F mixture. It is therefore possible to increase the maximum torque by compressing the air in the cylinder by means of dynamic supercharging, mechanical supercharging, or exhaust-gas turbocharging (P. 392).

Throttle map of an SI engine
– – – Intermediate position of throttle valve.



Torque curve for turbocharged engine compared with naturally aspirated engine at same rated power
1 Turbocharged engine, 2 Naturally aspirated engine.



Fuel delivery with electric fuel pump

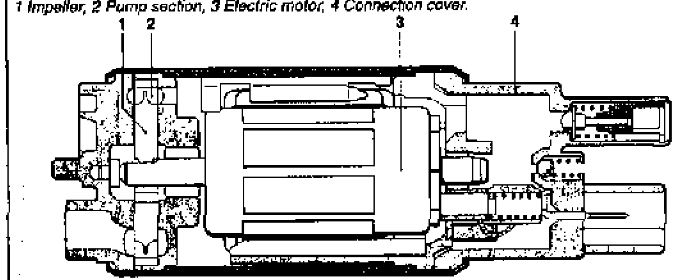
Function
The electric fuel pump must deliver sufficient quantities of fuel to the engine and maintain enough pressure for efficient injection under all operating conditions. Essential requirements include:
- maintaining flow rates between 60 and 200 liters/h at the rated voltage,
- maintaining fuel-system pressures of 300...450 kPa,
- the ability to pressurize the system during operation at 50...60% of the rated voltage, important for cold-starting response.

In addition, the electric fuel pump is increasingly being used as the presupply pump for modern direct-injection systems, both for gasoline and for diesel engines. For gasoline direct-injection systems, at times pressures of up to 700 kPa must to be provided. This, together with the very high viscosity range when pumping diesel fuel, signifies new challenges facing the hydraulic and electric systems of the electric fuel pump.

Design
The electric fuel pump consists of:
- the end cover including the electrical connections, non-return valve (to maintain system pressure) and the hydraulic discharge fitting. Most end covers also include the carbon brushes for the drive-motor commutator and interference-suppression elements (inductance coils, with condensers in some applications),
- the electric motor with armature and permanent magnets. Electronically commutated (EC) fuel pumps are being developed for use with special fuels which feature for instance marked electrolytic effects, and for use in other environments which have negative effects on carbon-brush and commutator assemblies.
- a positive-displacement or flow-type pump assembly.

Positive-displacement pump
As the positive-displacement unit's pump element rotates it draws in fluid through the suction side and through a sealed area on its way to the high-pressure side. Electric fuel pumps fall into two categories, the roller cell and the internal-gear unit. Positive-displacement pumps provide good performance in high-pressure (400 kPa and above) systems. They also perform well at low supply voltages, i.e. the flow rate curve remains relatively "flat" and constant throughout a wide range of operating voltages. Efficiency ratings can be as high as 25%. The unavoidable pressure pulses may cause noise; the extent of this problem varies according to the pump's design configuration and mounting location. Yet another disadvantage may be encountered with hot fuel, when the unit tends to pump gas instead of fuel, leading to reduced flow rates (problem potential varies according to in-

Electric fuel pump (example)
1 Impeller, 2 Pump section, 3 Electric motor, 4 Connection cover.



stallation location). Standard positive-displacement pumps usually incorporate peripheral primary circuits to deal with this problem by discharging the gas.

While the flow-type pump has to a large extent replaced the positive-displacement pump in electronic gasoline injection systems for performing the classical function of the electric fuel pump, a new field of application has opened up for the positive-displacement pump in terms of the above-mentioned presupply for direct-injection systems with their significantly increased pressure requirements and viscosity range. This is especially true for the presupply of diesel and biodiesel.

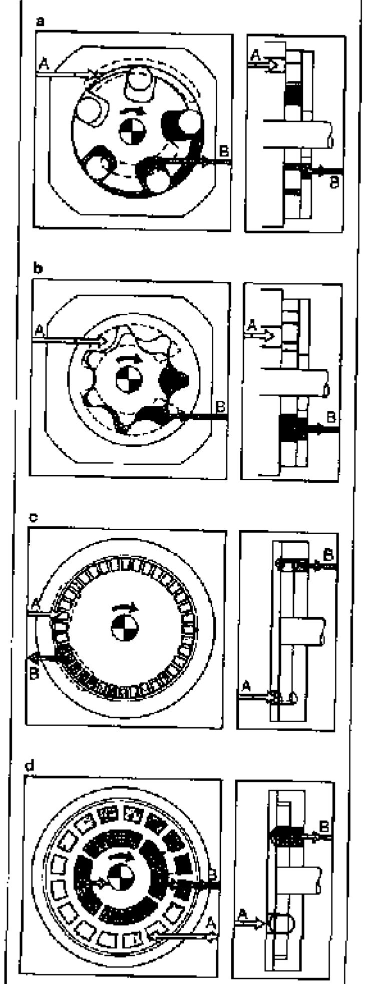
Flow-type pumps

Designs based on the principles used for the peripheral pump and the side-channel pump have become the standard for electric fuel pumps, with a slight preference for the side-channel pump as this tends to provide higher pressures and improved efficiency. An impeller equipped with numerous peripheral vanes rotates within a chamber consisting of two fixed housing sections. Each of these sections features a passage along the path of the impeller's vanes, with the openings on one end of the passage on a plane with the suction openings. From here they extend to the point where the fuel exits the pump at system pressure. Within the passage is a baffle element designed to prevent internal leakage. A small gas-discharge orifice (not necessary in diesel applications) located at a specified angular distance from the suction opening, improves performance when pumping hot fuel; this orifice facilitates the discharge of any gas bubbles which may have formed (with minimal leakage).

The pulses reflected between the impeller vanes and the fluid molecules result in pressurization along the length of the passage, inducing a spiral rotation of the fluid volume in the impellers and in the passages.

Because pressurization is continuous and virtually pulse-free, flow-type pumps are quiet in operation. Pump design is also substantially less complex than that of the positive-displacement unit. Single-stage pumps generate system pressures

Electric fuel-pump designs
a) Roller-cell pump,
b) Internal-gear pump,
c) Peripheral pump,
d) Side-channel pump.



extending up to 450 kPa. Still higher system pressures, as will become necessary for brief periods in future for highly supercharged engines, and for engines with gasoline direct injection (see above), are possible, but under continuous-duty conditions such pressures would overload today's conventional electrical systems (permanent-magnet DC motors with conventional electromechanical commutation) and would result in a significantly reduced service life. The following remedial measures are being considered:

- High-pressure operation only when required → demand control of the electric fuel pump, e.g. with the aid of a timing module or another upstream device.
- Equipping of the fuel-pump motor with a carbon commutator in place of the conventional copper commutator so as to safeguard the service life also at high current and additionally with corrosive and/or high-viscosity fuels.
- For applications where the wide range of operating conditions and fuels place particularly high demands on the pump's versatility, work is proceeding on electronically commutated (EC) fuel-pump drives. Such an electrical system features unlimited service life.

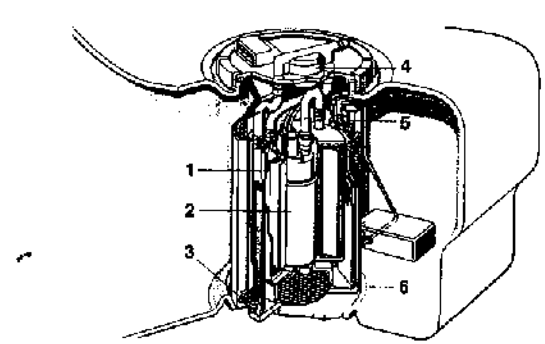
The efficiency ranges between 10 and approx. 20 %. The fuel systems of newly designed vehicles with spark-ignition engines rely almost exclusively on flow-type pumps for fuel delivery.

Electric fuel pumps: Integration in injection system and in fuel tank

Whereas the first electronic fuel-injection systems almost always featured electric fuel pumps designed for in-line installation outside the tank, current and more recent applications tend to have in-tank installation as a standard feature. The electric fuel pump is one of the elements within the in-tank units now being designed to include an increasingly wide array of components such as: the suction filter, a fuel-baffle chamber to maintain delivery during cornering (usually with its own "active" supply based on a suction-jet pump or a separate primary circuit in the main electric pump), the fuel gauge sensor, and a variety of electrical and hydraulic connections.

Another advance is the returnless fuel system (RLFS), usually in the form of an in-tank unit with an integral fuel-pressure regulator designed to maintain a continuous return circuit within the in-tank assembly. A pressure-side fine-mesh fuel filter can also be incorporated in this unit. Further functions will in future be integrated in the delivery module, e.g. diagnostic devices for tank leakage, timing module for fuel-pump control.

In-tank unit: complete integrated assembly for returnless fuel systems
1 Fuel filter, 2 Electric fuel pump, 3 Suction-jet pump (regulated), 4 Fuel-pressure regulator, 5 Fuel-gauge sensor, 6 Suction strainer.



A/F-mixture formation

Influencing variables

Air-fuel (A/F) mixture
To be able to operate, a spark-ignition engine requires a specific air-fuel mixture ratio. Ideal theoretical complete combustion is available at a mass ratio of 14.7:1. This is also termed the stoichiometric ratio. I.e.: an air mass of 14.7 kg is needed to burn a fuel mass of 1 kg. Or expressed as a volume: 1 l fuel burns completely in roughly 9500 l air.

The specific fuel consumption of a spark-ignition engine is essentially dependent on the mixture ratio of the A/F mixture. It is necessary to have an excess of air in order to ensure genuine complete combustion, and thus as low a fuel consumption as possible. Limits are imposed though by the flammability of the mixture and the available combustion time.

The A/F mixture also has a decisive impact on the efficiency of the exhaust-gas treatment systems. State-of-the-art technology is represented by the three-way catalytic converter. This, though, needs a stoichiometric A/F ratio in order to operate with maximum efficiency. Such a catalytic converter helps to reduce harmful exhaust-gas constituents by more than 98%.

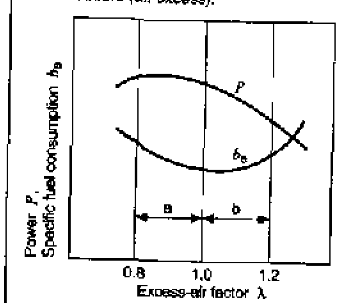
The engines available today are therefore operated with a stoichiometric mixture as soon as their operating status permits this.

Certain engine operating states require mixture corrections. Specific corrections of the mixture composition are necessary e.g. when the engine is cold. The mixture-formation *(carburation) system must* therefore be in a position to satisfy these variable requirements.

Excess-air factor
The excess-air factor λ (lambda) has been chosen to designate the extent to which the actual air-fuel mixture differs from the theoretically necessary mass ratio (14.7:1):
λ = Ratio of supplied air mass to air requirement with stoichiometric combustion.
$\lambda = 1$: The supplied air mass corresponds to the theoretically necessary air mass.
$\lambda < 1$: There is an air deficiency and thus a rich mixture. Maximum power output at $\lambda = 0.85...0.95$.
$\lambda > 1$: There is an excess of air or a lean mixture in this range. This excess-air factor is characterized by reduced fuel consumption and reduced power output. The maximum value for λ that can be achieved – the so-called "lean-burn limit" – is very heavily dependent on the engine design and on the mixture-formation system used. The mixture is no longer ignitable at the lean-burn limit. Combustion misses occur and this is accompanied by a marked increase in uneven running.

Spark-ignition engines with manifold injection achieve their peak power output at an air deficiency of 5...15% ($\lambda = 0.95...0.85$), and their lowest fuel consumption at an air excess of 10...20% ($\lambda = 1.1...1.2$).

Effect of excess-air factor λ on power P and specific fuel consumption b_e.
a Rich mixture (air deficiency),
b Lean mixture (air excess).



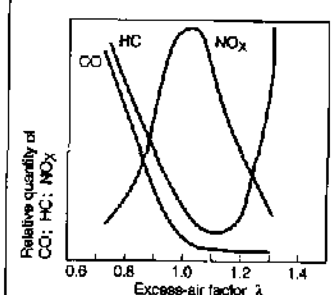
The graphs show the dependence of power output, specific fuel consumption and pollutant buildup on the excess-air factor for a typical engine with manifold injection. It can be deduced from these graphs that there is no ideal excess-air factor at which all the factors assume the most favorable value. For engines with manifold injection, excess-air factors of $\lambda = 0.9...1.1$ have proven effective in realizing "optimal" consumption at "optimal" power output.

Engines with direct injection and charge stratification involve different combustion conditions such that the lean-burn limit is significantly higher. These engines can therefore be operated in the part-load range with significantly higher excess-air factors (up to $\lambda = 4$).

For the treatment of exhaust gas by a three-way catalytic converter, it is absolutely essential to adhere exactly to $\lambda = 1$ with the engine at normal operating temperature. In order to do so, the air mass drawn in must be precisely determined and an exactly metered fuel mass added to it.

For optimum combustion in today's common manifold-injection engines, not only is a precise injected fuel quantity necessary, but also a homogeneous A/F mixture. This necessitates efficient fuel atomization. If this precondition is not satisfied, large fuel droplets will precipitate on the intake manifold or the combustion-chamber walls. These large droplets cannot fully combust and will result in increased hydrocarbon emissions.

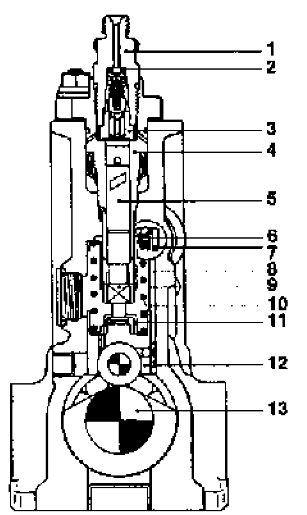
Effect of excess-air factor λ on pollutant composition in untreated exhaust gas



Mixture-formation systems
It is the job of fuel-injection systems, or carburetors, to furnish an A/F mixture which is adapted as well as possible to the relevant engine operating state. Injection systems, especially electronic systems, are better suited to maintaining narrowly defined limits for the mixture composition. This is advantageous with regard to fuel consumption, driving performance and power output. The result of increasingly stringent exhaust-emissions legislation in the automotive sector is that today, injection systems have completely superseded carburetors.

Today, the automotive industry almost exclusively uses systems in which the mixture formation takes place outside the combustion chamber. However, systems with interior mixture formation, i.e. where the fuel is injected directly into the combustion chamber, already formed the basis of the first gasoline injection systems. These systems are increasing in importance as they are very well suited to reducing fuel consumption even further.

Size P in-line fuel-injection pump
1 Delivery-valve holder, 2 Spring seat, 3 Delivery valve, 4 Pump barrel, 5 Pump plunger, 6 Lever arm with ball head, 7 Control rack, 8 Control sleeve, 9 Plunger control arm, 10 Plunger return spring, 11 Spring seat, 12 Roller tappet, 13 Camshaft.



In-line fuel-injection pump (PE)

Fuel-supply pump

A piston pump delivers the fuel to the injection pump's fuel gallery at a pressure of 1...2.5 bar. The cam-driven supply-pump plunger travels to TDC on every stroke. It is not rigidly connected to the drive element; instead, a spring supplies the return pressure. The plunger spring responds to increases in line pressure by reducing the plunger's return travel to a portion of the full stroke. The greater the pressure in the delivery line, the lower the delivery quantity.

High-pressure pump

Every in-line fuel-injection pump has a plunger-and-barrel assembly (pumping element) for each engine cylinder. An engine-driven camshaft moves the plunger in the supply direction, and a spring presses it back to its initial position. Although the plunger has no seal, it is fitted with such precision (clearance: 3...5 µm) that its operation is virtually leak-free, even at high pressures and low engine speeds.

The plunger's actual stroke is constant. The delivery quantity is changed by altering the plunger's effective stroke. Inclined helices have been machined into the plunger for this purpose, so that the plunger's effective stroke changes when it is rotated. Active pumping starts when the upper edge of the plunger closes the intake port. The high-pressure chamber above the plunger is connected by a vertical groove to the chamber below the helix. Delivery ceases when the helix uncovers the intake port.

Various helix designs are employed in the plunger. On plunger-and-barrel assemblies with a lower helix only, pumping always begins at the same stroke travel, the plunger being rotated to advance or retard the end of delivery. An upper helix can be employed to vary the start of delivery. There are also plunger-and-barrel assemblies on the market which combine upper and lower helices in a single unit.

In order of their suitability for use with high injection pressures, the major types of delivery valve currently in use are:
- Constant-volume valve,
- Constant-volume valve with return-flow restriction,
- Constant-pressure valve.

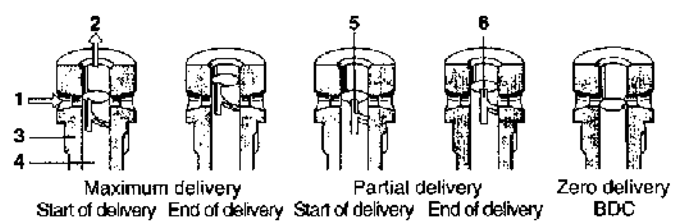
The delivery valve and pressure-relief characteristics must be specially designed for the specific application. Units incorporating a return-flow restriction or constant-pressure valve have an additional throttle element to damp the pressure waves reflected back from the injection nozzle, thus preventing it from opening again. The constant-pressure valve is employed to maintain stable hydraulic characteristics in high-pressure fuel-injection systems and on small, high-speed direct-injection engines.

In fuel-injection pumps which generate moderate pressures of up to 600 bar (e.g. Size A), the plunger-and-barrel assembly is installed in the pump housing in a fixed position, where it is held in place by the delivery valve and the delivery-valve holder.

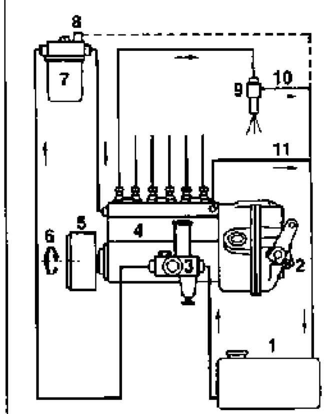
In pumps which generate injection pressures greater than approx. 600 bar, the plunger-and-barrel assembly, delivery valve and delivery-valve holder are screwed together to form a single unit, which means that the high sealing forces must no longer be accommodated by the pump housing (e.g. Sizes MW, P).

The in-line fuel-injection pump and the attached governor are connected to the engine's lube-oil system.

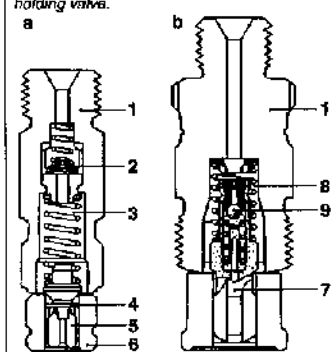
Fuel-delivery control in the in-line fuel-injection pump
1 From fuel gallery, 2 To nozzle, 3 Barrel, 4 Plunger, 5 Lower helix, 6 Vertical (stop) groove.



In-line fuel-injection pump with mechanical (flyweight governor)
1 Fuel tank, 2 Governor, 3 Fuel-supply pump, 4 Injection pump, 5 Timing device, 6 Drive from engine, 7 Fuel filter, 8 Vent, 9 Nozzle-and-holder assembly, 10 Fuel return line, 11 Overflow line.

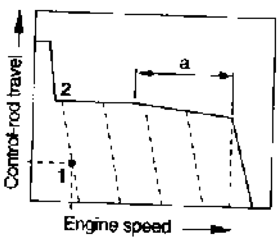


Delivery-valve holder with delivery valve
a) With constant-volume valve and return-flow restriction, b) With constant-pressure valve. 1 Delivery-valve holder, 2 Return-flow restriction, 3 Dead volume, 4 Retraction piston, 5 Valve ball, 6 Valve holder, 7 Supply valve, 8 Calibrated restriction, 9 Pressure-holding valve.

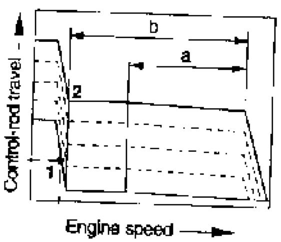


Governor characteristic curves
a Positive torque control in upper speed range, b Unregulated range, c Negative torque control.
1 Idle-speed setpoint, 2 Full-load curve, 3 Full-load curve, turbocharged engine, 4 Full-load curve, naturally-aspirated engine, 5 Full-load curve, naturally-aspirated engine with altitude compensation, 6 Intermediate engine-speed control, 7 Temperature-sensitive starting quantity.

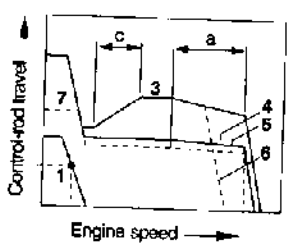
Variable-speed governor



Minimum-maximum-speed governor



Complex governor with additional control functions



Speed governing
The main function of the governor is to li[mit] the maximum engine speed. In ot[her] words, it must ensure that the diesel e[n]gine does not exceed the maximum mi[n⁻¹] specified by its manufacturer. Dependi[ng] upon type, the governor's functions may i[n]clude maintaining specific, constant e[n]gine speeds, such as idle, or other speed[s] in the range between idle and maximu[m] speed. The governor can also adjust fu[ll-]load delivery in accordance with engin[e] speed (adaptation), boost or atmospheri[c] pressure, and it can be used to meter th[e] extra fuel required for starting. The gove[r]nor adapts the delivery quantity to thes[e] conditions by making corresponding ad[]justments in the position of the control rack.

Mechanical (flyweight) governors
The mechanical governor (also known as a flyweight or centrifugal governor) is driven by the engine's camshaft, and provides the performance curves described below. The flyweights, which act against the force of the governor springs, are connected to the control rack by a system of levers. During steady-state operation, centrifugal and spring forces are in a state of equilibrium, and the control rack assumes a position for fuel delivery corresponding to engine power output at that operating point. A drop in engine speed – for instance, due to increased load – results in a corresponding reduction in centrifugal force, and the governor springs move the flyweights, and with them the control rack, in the direction for increased delivery quantity until equilibrium is restored. Various functions are combined to produce the following types of governor:

Variable-speed governors
The variable-speed governor maintains a virtually constant engine speed in accordance with the position of the control lever. Applications: Preferably for commercial vehicles with auxiliary power take-off, for construction machinery, agricultural tractors, in ships and in stationary installations.

Minimum-maximum-speed governors
From the characteristic curve for the minimum-maximum-speed governor it can be seen that this type of governor is effective only at idle and when the engine reaches

maximum min⁻¹. The torque in the range between these two extremes is determined exclusively by the position of the accelerator pedal. Applications: For road vehicles.

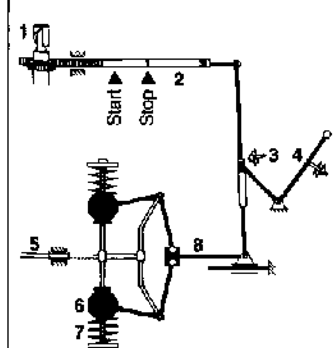
Combination governors
Combination governors are a synthesis of the two governor types described above. Depending upon the specific application, active control can be in the upper or lower engine-speed range.

Governor types
In the RQ and RQV governor, the flyweights act directly on the governor springs, and control-lever movements vary the transfer ratio at the fulcrum lever.
In the RSV and RSF governor, the governor spring is outside the flyweights; the transfer ratio at the fulcrum lever remains essentially constant.

Speed droop
The governor's performance characteristics are essentially a function of the slope of the control curve, defined as speed droop:

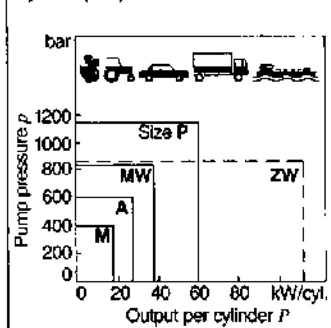
$$\delta = \frac{n_{LO} - n_{VO}}{n_{VO}} \cdot 100\,\%$$

RQ Minimum-maximum-speed governor
1 Pump plunger, 2 Control rack, 3 Full-load stop, 4 Control lever, 5 Injection-pump camshaft, 6 Flyweight, 7 Governor spring, 8 Sliding bolt.



The smaller the difference between the upper no-load speed (n_{LO}) and the upper full-load speed (n_{VO}), the lower the speed droop, i.e. the greater the precision with which the governor maintains a specific engine speed. Variable-speed governors in small high-speed engines generally achieve a full-load speed regulation (top-end breakaway consistency) of 6...10 %.

Applications for various types of in-line injection pump



RSV Variable-speed governor
1 Pump plunger, 2 Control rack, 3 Maximum-speed stop, 4 Control lever, 5 Start spring, 6 Stop or idle stop, 7 Governor spring, 8 Auxiliary idle spring, 9 Injection-pump camshaft, 10 Flyweight, 11 Sliding bolt, 12 Torque-control spring, 13 Full-load stop.